No-Failure Design
and
Disaster Recovery

Lessons from Fukushima

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Contents

1 *Highlights*

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2 Lessons of Fukushima: No-Failure Design and Disaster Recovery

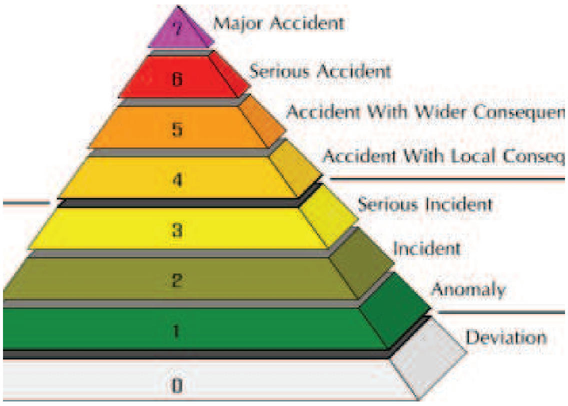

Figure 1: **Int'l Nuclear Event Scale.** (Wikipedia)

§ Nuclear plant accidents:

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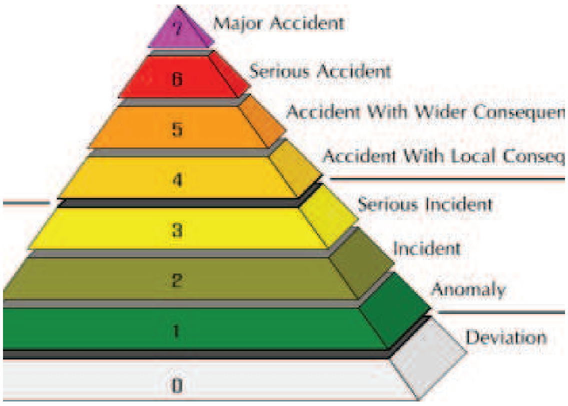

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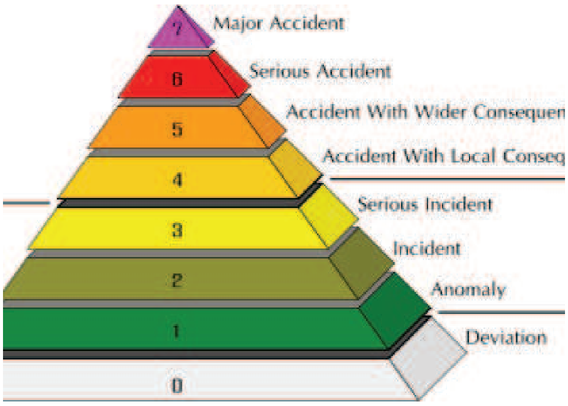

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- **Serious (INES 6):**
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- **With wider consequences (INES 5):**
  - **Windscale fire, UK, 10.10.1957**
  - **3 Mile Island, Harrisburg, PA, 28.3.1979.**
  - **Lucens partial core meltdown (Switzerland), 21.1.1969**
  - **Others.**

§ Approx nuclear power statistics (Aug 2011):

- **432 reactors in 30 countries (ENS).**[‡]
- **366GWe installed capacity (ENS).**
- **14,570 reactor years of experience (ENS).**
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[†] This is probably a substantial under-estimate. The numerator is too small: 3 reactors were seriously damaged, not 1. The denominator is too large: we should only take reactor-years from industrial democracies.

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§ Are there more lessons or challenges from Fukushima?

3 *Science-Based Modeling*

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§ **We must understand the modern attitude: strengths and limitations.**

Fundamental Physics

Maxwell's Equations

Figure 4: **James Clerk Maxwell, 1831–1879.**

$$\nabla \cdot E = \frac{\rho}{\varepsilon} \qquad \nabla \cdot B = 0$$

$$\nabla \times E = -\frac{\partial B}{\partial t} \qquad \nabla \times B = \mu J + \mu\varepsilon\frac{\partial E}{\partial t}$$

- **Positivism: From basic science to technology:**
  Radio, X-ray diagnosis, CAT scan,
  wifi, remote sensing, ...

- **Engineering education: sciences not crafts.**

Empirical Physics

Finite Element Modeling

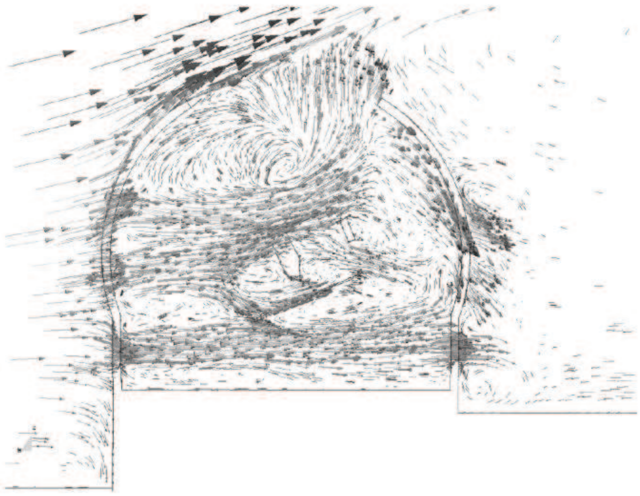
Figure 7: Example of velocity field on the vertical mid section

Figure 5: **Velocity field around a structure.**‡

- **If we know the physics**

  we can

  calculate anything.

- **Methodology: simulation vs experiment.**

‡R. Codina, C. Morton, E. Oñate and O. Soto, http://www.cimne.com/eo/publicaciones/files/PI181.pdf

Computational Social Science

Econometric Modeling


$$\frac{\mathrm{d}u(c_t)}{\mathrm{d}c_t}p_{1t} = \beta\frac{\mathrm{d}u(c_{t+1})}{\mathrm{d}c_{t+1}}(1-\widehat{\alpha}\phi_t)\widetilde{y}_{1,t+1}$$
$$\frac{\mathrm{d}u(c_t)}{\mathrm{d}c_t}p_{2t} = \beta\frac{\mathrm{d}u(c_{t+1})}{\mathrm{d}c_{t+1}}y_{2,t+1}$$

Figure 6: **$100, US GDP growth,[‡] Lucas asset pricing model.**

- **From the dry science**

  to

  policy formulation.

- **Methodology: social engineering.**

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[‡] Saul H. Hymans, Forecasting and Econometric Models, The Concise Encyclopedia of Economics, http://www.econlib.org/library/Enc/ForecastingandEconometricModels.html

Computational Megalomania?

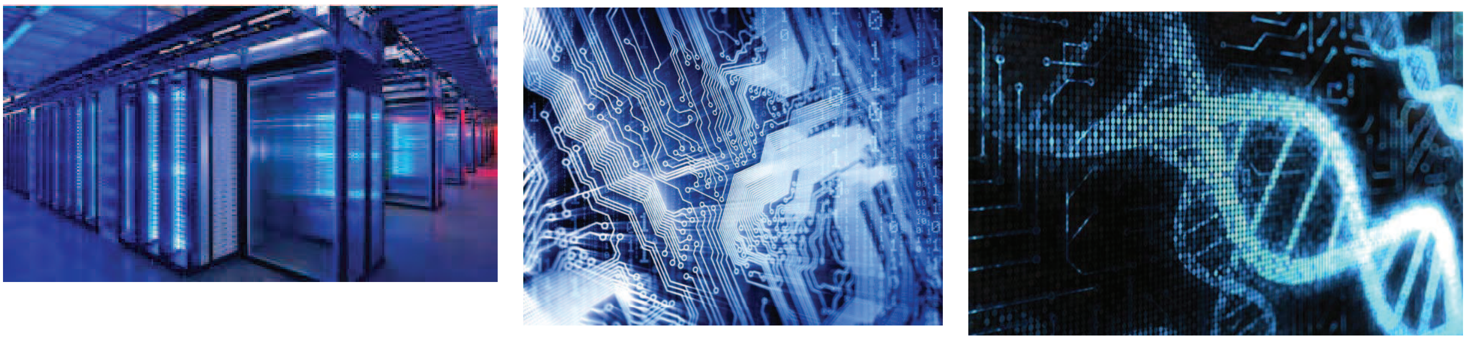

Figure 7: **Computers and their aspirations.**

- **If you can't measure it, it's not real (logical positivism).**
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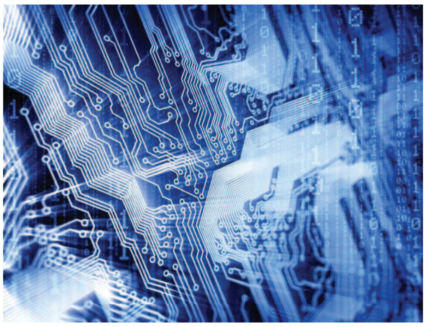


Figure 8: **Computers and their aspirations.**

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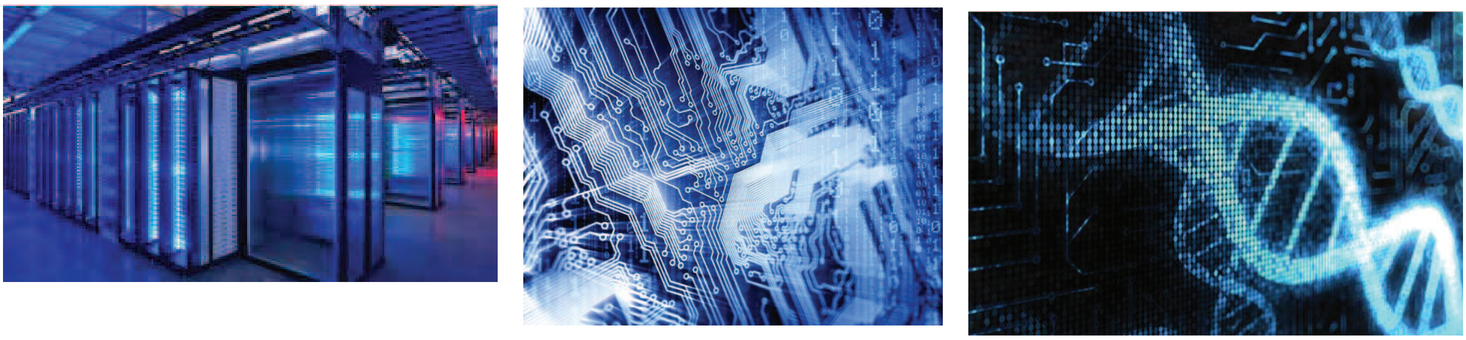

Figure 9: **Computers and their aspirations.**

- **If you can't measure it, it's not real (logical positivism).**
- **If it's not a number, it's not important. (What about meaning?)**
- **We can compute anything. (Archimedes' modern lever?)**

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§ Quantitative model types:

- **Fundamental physics.**
- **Empirical physics.**
- **Computational social science.**
- **Computational megalomania?**

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§ **The challenge:**

Uncertainty, surprise, ignorance, change.

Info-gaps.

4 Info-Gap Uncertainty: Examples

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∼∼*Thames Flood Barrier*∼∼

Figure 10: **1953 barrier breach.**

Figure 11: **Barrier element.**

§ Some facts:

- **1953: worst storm surge of century.**
- **Flood defences breached.**
- **307 dead. Thousands evacuated.**
- **Canvey Island in Estuary devastated.**
- **Current barrier opened May 1984.**

§ **Thames 2100:**

Major re-design of flood defences.

§ **Uncertainties:**

- **Statistics of surge height:**
  - **Fairly complete: most years since 1819.**
  - **Planning for 1000-year surge.**
- **Global warming: sea level rise.**
- **Tectonic settling of s. England.**
- **Damage vs flood depth.**
- **Human action: dredging, embanking.**
- **Urban development.**

§ **Severe Knightian uncertainties: Gaps in knowledge, understanding and goals.**

∼∼*Fukushima Nuclear Reactor*∼∼

Figure 12: **Sea wall breach.**

Figure 13: **Hydrogen explosion.**

§ Some facts:

- **11.3.2011: Richter-9 earthquake in NE Japan.**
- **Tsunami followed shortly.**
- **Sea wall breached: fig. 12.**‡
- **Hydrogen explosion several days later. Fig. 13.**‡
- **Slow disaster recovery.**

§ Info-gaps:

- **Sub-system interactions.**
- **Institutional constraints.**

‡ http://www.dailymail.co.uk/news/article-1388629/Japan-tsunami-destroyed-wall-designed-protect-Fukushima-nuclear-plant.html

∼∼*Assay Spatially Random Material*∼∼

Figure 14: **Nuclear Waste.**

Figure 15: **Gold Ore Vein.**

- **Detector type, location, number?**
- **Info-gaps:**
  - **Spatial distribution of analyte.**
  - **Spatial heterogeneity of matrix.**

∼∼Interest rate after 9/11∼∼

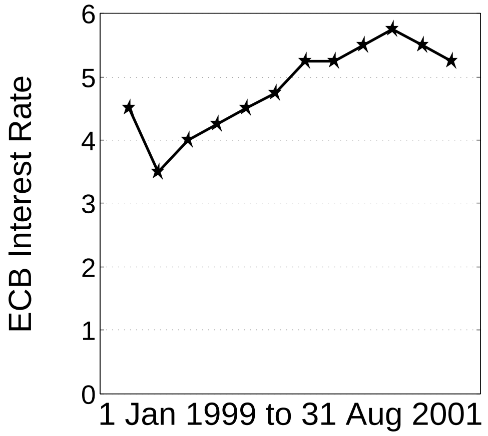

Figure 16: **ECB Interest Rates**

- **Rate fairly constant through Aug 2001**

∼∼*Interest rate after 9/11*∼∼

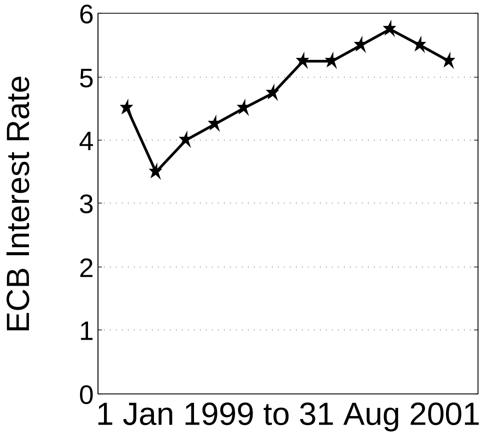

Figure 17: **ECB Interest Rates**

Figure 18: **11 Sept 2001.**

- **Rate fairly constant through Aug 2001**
- **After 9/11 ECB will reduce the rate.**
- **Info-gap:**
  - **Reduce by how much?**
  - **What is ECB decision model?**

∼∼*Climate Change*∼∼

§ The issue:

Sustained rise in green house gases

results in temperature rise

which results in adverse economic impact.

§ Models:

- Temperature change: $\Delta \mathrm{CO}_2 \Longrightarrow \Delta T$.
- Economic impact: $\Delta T \Longrightarrow \Delta \mathrm{GDP}$.

§ The problems:

- Models highly uncertain.
- Data controversial.

§ E.g., IPCC model for

Uncertainty in Equil'm Clim. Sensi'ty, S.

- **Likely range: 1.5$^{\mathrm{o}}$C to 4.5$^{\mathrm{o}}$C.**
- **Extreme values highly uncertain.**
- **95th quantile of S in 10 studies:**

  Mean: 7.1$^{\mathrm{o}}$C. St. Dev: 2.8$^{\mathrm{o}}$C.

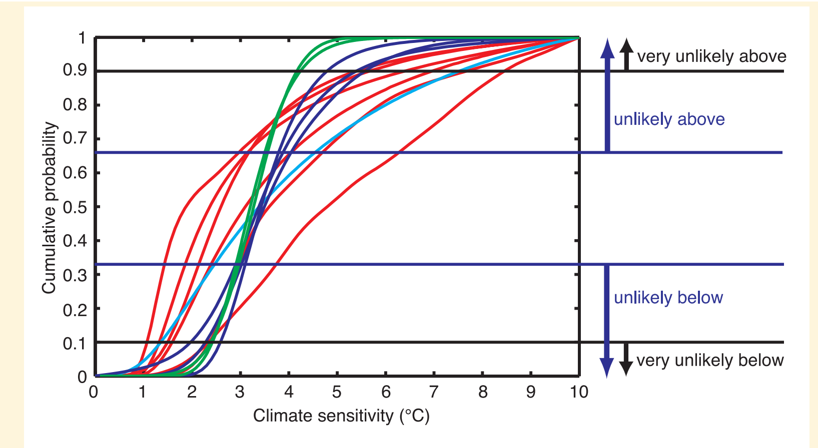

Figure 19: IPCC ch.10, p.799.

∼∼*Profiling Criminals*∼∼

Figure 20: **Profiling raises arrests.**

- **Profiling: focus policing resources.**
  - **Arrests rise in profiled group.**
  - **Crime rises in other groups.**
  - **Everybody happy?**
- **Info-gaps: Uncertain response functions.**

∼∼*Summary*∼∼

§ **Severe Knightian uncertainties: Gaps in knowledge, understanding and goals.**

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§ **Severe Knightian uncertainties:** **Gaps in knowledge, understanding and goals.**

§ **Info-Gap models of uncertainty:**

- **Disparity between what is known and what needs to be known for responsible decision.**
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§ **Severe Knightian uncertainties:** Gaps in **knowledge, understanding** and **goals.**

§ **Info-Gap models of uncertainty:**

- **Disparity between what is known and what needs to be known for responsible decision.**
- **Unbounded family of sets of events (points, functions or sets).**
- **No known worst case.**
- **No funcs. of probability, plausibility, likelihood, etc.**
- **Hybrid: info-gap model of probabilities.**

5 *Innovation Dilemma*

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§ Choose between two options:

- **Option 1:**
  - **Innovative, promising, new technology.**
  - **Higher uncertainty because it's new.**
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§ **Choose between two options:**

- **Option 1:**
  - **Innovative, promising, new technology.**
  - **Higher uncertainty because it's new.**
- **Option 2:**
  - **Standard. State of the art.**
  - **Lower uncertainty because it's well known.**

§ Examples of the innovation dilemma:

- **Automotive collision control:**
  - **Sensor-based computer control (innov).**
  - **Reliable effective breaking system (SotA).**
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- **Eradicate invasive species:**
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- **Nurture economic growth in 3rd world:**
  - Human capital, institutions (innov).
  - Import technology, infrastructure (SotA).
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- **Automotive collision control:**
  - Sensor-based computer control (innov).
  - Reliable effective breaking system (SotA).
- **Eradicate invasive species:**
  - New aerial pesticide (innov).
  - Port quarantine (SotA).
- **Nurture economic growth in 3rd world:**
  - Human capital, institutions (innov).
  - Import technology, infrastructure (SotA).
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- **Risk taking or avoiding:**
  - Nothing ventured, nothing gained (innov).
  - Nothing ventured, nothing lost (SotA).

§ Decision strategies.

- **Outcome optimization:**
  - **Use models to predict outcomes.**
  - **Choose predicted best option.**
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§ Question:

Which strategy suitable for innovation dilemma?

6 *Thames Flood Barrier*

Figure 21: **1953 barrier breach.**

Figure 22: **Barrier element.**

§ Some facts:

- **1953: worst storm surge of century.**
- **Flood defences breached.**
- **307 dead. Thousands evacuated.**
- **Canvey Island in Estuary devastated.**
- **Current barrier opened May 1984.**

§ Thames 2100:

Major re-design of flood defences.

§ Uncertainties:

- Statistics of surge height:
  - Fairly complete: most years since 1819.
  - Planning for 1000-year surge.
- Damage vs flood depth.
- Global warming: sea level rise.
- Human action: dredging, embanking.
- Urban development.
- Tectonic settling of s. England.

§ **Design requirement:**

Small probability of large damage.

§ **Decision:** **choose a design.**

§

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- **Our goals may be unclear, conflicting.**

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§ **Design strategy: Robust satisficing.**

- **How wrong can we be, and the design is still adequate? (Satisficing.)**
- **How large a surprise can the design tolerate? (Robustness.)**

§ Innovation dilemma.

- **Design 1:**
  - **Innovative technology.**
    - — **Early warning system.**
    - — **Adaptive channeling.**
  -

§ Innovation dilemma.

- **Design 1:**
  - **Innovative technology.**
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  - **Predicted prob of excess damage: tiny.**
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- **Design 1:**
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    - — **Solid dykes.**
    - — **Hydraulic barriers.**
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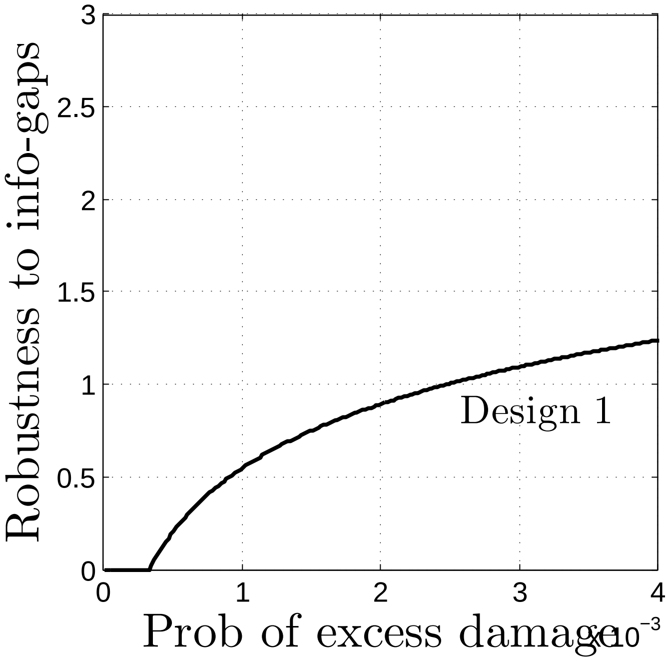
§ Choose design 1? Design 2?

- **Responsible decision?**
- **Robust to ignorance?**

§ Robustness to info-gaps vs Probability of excess damage. Design 1



§ Trade off:

Less demanding outcome has greater robustness.

§

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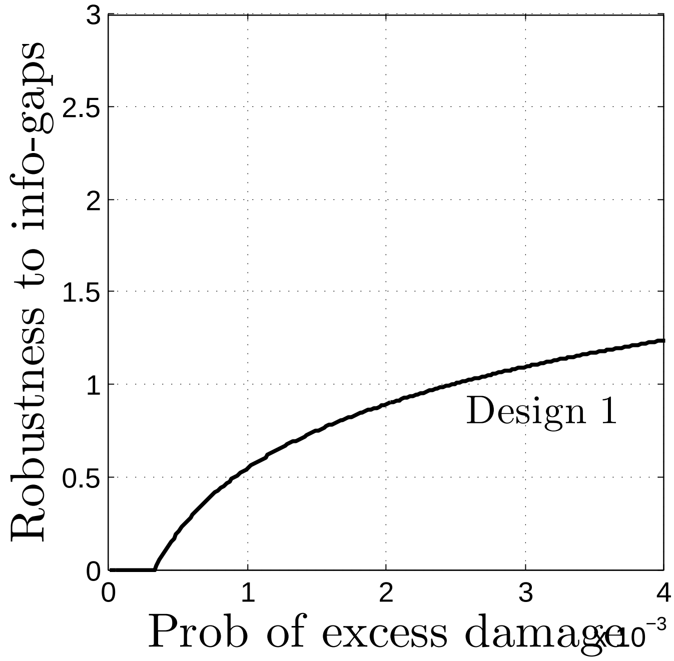


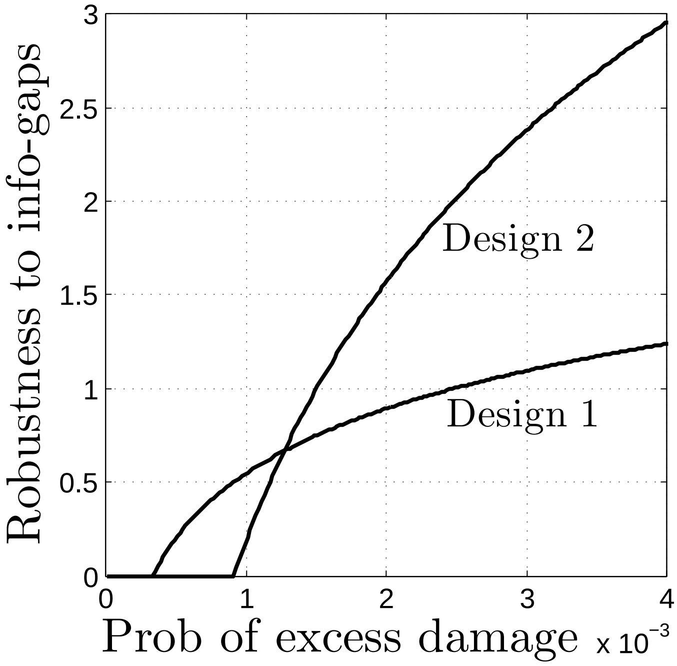
§ Trade off:

Less demanding outcome has greater robustness.

§ Zeroing:

Estimated outcome has zero robustness.

§ Comparing 2 designs.

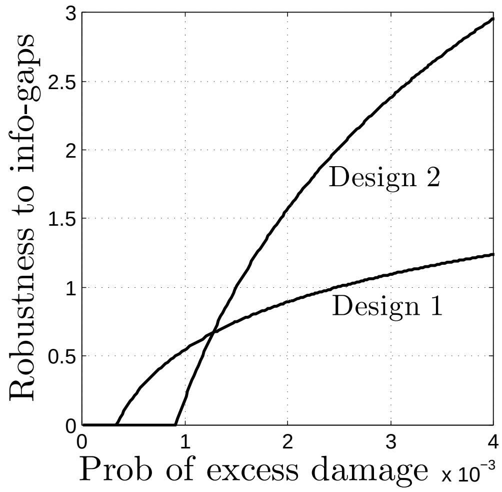


§ **Design 1 (innov) estimated to be better.**
Zero robustness of estimates.

§ **Design 2 (SotA) more robust for** $P > P_{\times}$.

§ **Innovation dilemma.**

§ Optimize or robust-satisfice?



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- **Predict best-outcome design.**

§

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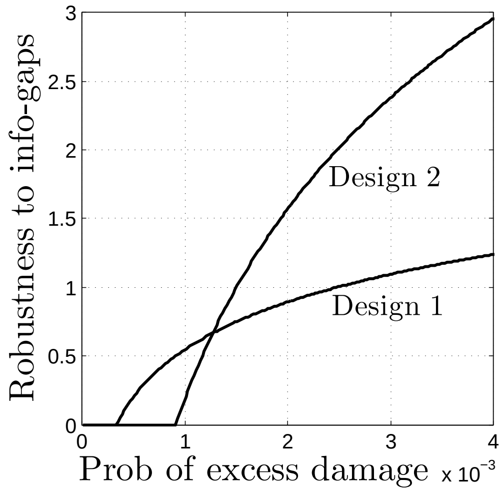

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§ Robust-satisficing:

- **Identify critical outcome.**
- **Maximize rbs of critical outcome.**

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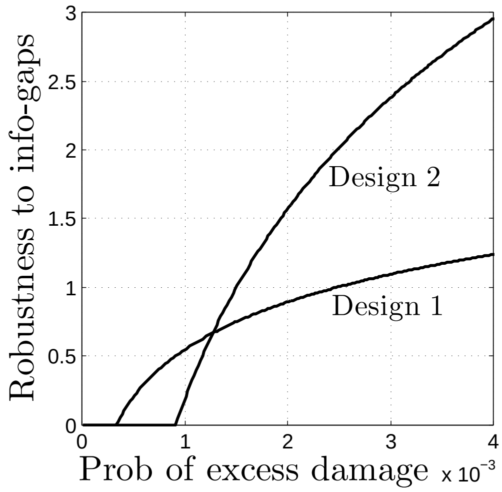

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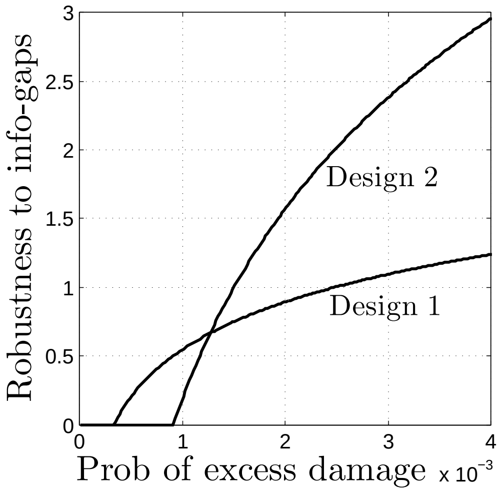

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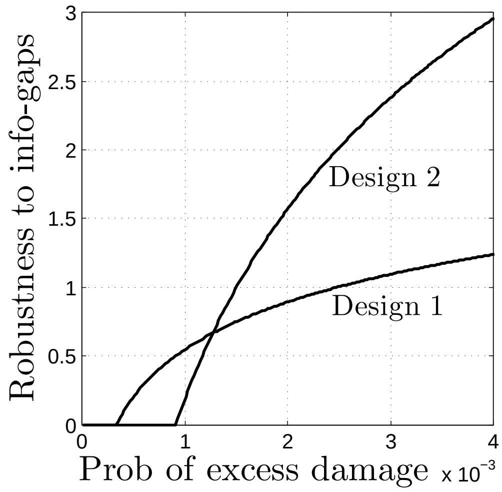

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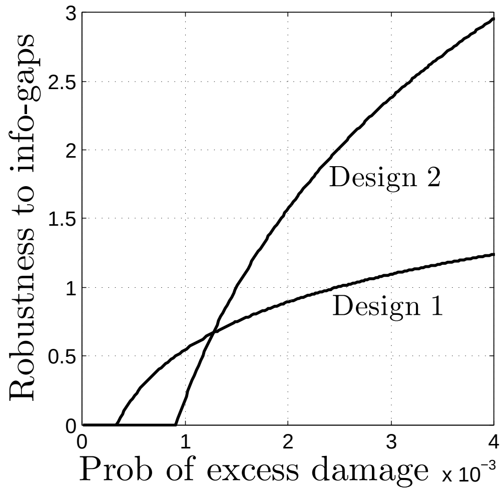
§ Resolve innovation dilemma:

- **Value judgment on outcome requirement.**
- **Robustly satisfy requirement.**

§ Optimize or robust-satisfice?



§ Robust-satisficing strategy:

Robustly satisfy performance requirement.

§ Question:

Is robustness a good bet?

7 Conclusion

§ **Lessons:**

- **Design for no-failure.**
- **Prepare Disaster Recovery Capability.**

§

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- **Why do we need DRC if we do No-Fail Design?**
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  - Can we reliably predict performance?

§ Closing question:

No-fail design and disaster recovery capability are both necessary for critical technology.

How to decide the technology is feasible?